AN INTRO TO

Wiring Harnesses

An Introductory Guide for Engineers Designing Aircraft Wiring Harnesses
January 1, 2014

John Ashour
- President, InterConnect Wiring -

A Publication of
InterConnect

TABLE OF CONTENTS

Introduction

- The purpose of this eBook is to provide some general guidance to new aerospace engineers who are tasked in designing electrical wiring harnesses. The emphasis is on military aircraft but many of the guidelines are also true for commercial aircraft.

- InterConnect is not aware of any similar document on this subject. Typically in the industry, each Original Equipment Manufacturer (OEM) makes their own guidelines and passes that information on to their engineers. Hopefully, over the years and after numerous comments and feedback from many design engineers this document can become an industry standard.

Introduction

- These guidelines are based on over 25 years experience in the industry and are what InterConnect has identified as best practices from OEM's such as: Lockheed Martin, The Boeing Company, Sikorsky Aircraft, Bell Helicopter, BAE, and the Joint Services Wiring Action Group (JSWAG). No proprietary information is presented in this EBook. It contains only general information used throughout the military aerospace wiring harness industry.

The eBook covers the following topics in the order listed:

- ✓ Wire Harness Design – Where to Start
- ✓ Standard Versus Non-Standard Parts Versus Commercial Off The Shelf (COTS) Parts
- ✓ Wire Selection
- ✓ Wire Identification
- ✓ Connector Selection
- ✓ Shield Termination
- ✓ Reference Designators
- ✓ Harness Bundle Protection
- ✓ Testing
- ✓ Industry Standards

CHAPTER

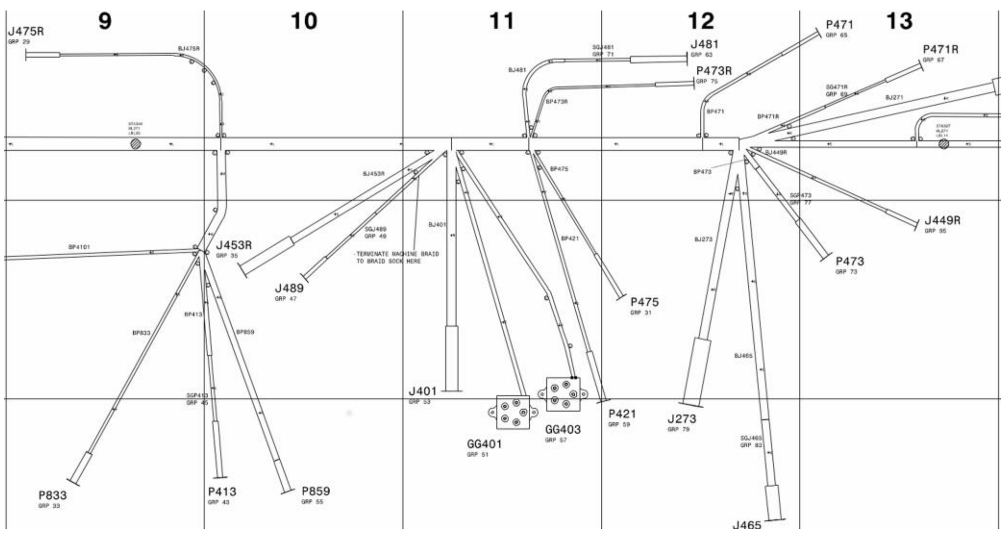
1

Wire Harness Design – Where to Start

- So you are a new engineer freshly out of college. You get hired at a large OEM to design electrical wiring harnesses and wired box assemblies. Not having the proper training in college you ask yourself, “Where do I start?”. The possibilities are limitless. Luckily you can do a Google search and find this eBook under InterConnect Wiring’s home page. After a quick examination you download it and begin reading.

- Typically each aircraft has a specification called an Air Vehicle Specification (AVS). This is a very large document that the OEM writes prior to designing the aircraft. It includes tons of information about the aspects of an aircraft. Some of that information includes wiring harness design. Ask an experienced engineer or your boss if there is an AVS or similar document. If there is, get a copy, look through the table of contents and find and read sections that deal with electrical systems design.

- The next piece of information you need is the wiring harness military specification that most military aircraft comply with. This specification is SAE AS50881 (at one time it was MIL-STD-5088) “Wiring Aerospace Vehicle”. This specification covers information such as: wire current carrying capacity, how wires are identified, marked, routed, and supported in military aircraft, and hundreds of other necessary guidelines and requirements. Download a copy of this document, read it and keep it handy for further use. You can find it at www.sae.org.



CHAPTER

2

Standard Versus Non-Standard Versus COTS Parts

- During the wiring harness design process, there are thousands of different part numbers to select from. You ask yourself, how do I decide which parts to select? The subsequent chapters in this eBook provide information on how to select parts. Prior to reading those chapters, it is important to understand the following topics:

  - Standard Parts
  - Non-Standard Parts
  - COTS parts

- A *standard part* is a military part. It is controlled by the US military (typically the Navy in Philadelphia, PA). These parts are often called mil spec parts (short for military specification). Many of these part numbers start with "M" which is short for military.

- An example: is M39029/4-110. This is a military contact part number that is inserted into contact cavities of military connectors. some military part numbers start with "MS" which stands for military specification.

- Another example is MS3154 which is a backshell or strain relief for wires that enter a connector. Other prefixes include “NAS” which stands for National Aerospace Standard. An example is NAS514 which is a screw. There are other military part number prefixes but these are the most common for the wiring harness design industry.

- Each military part number has a specification associated with it. These specifications are available on-line at http://www.dscc.dla.mil/programs/MilSpec/DocSearch.aspx. Since around the late 1990’s the control of the specification has been transferred from the US Navy to the Society of Automotive Engineers.

- One good thing about military parts is that they are common across many aerospace platforms (i.e. many different aircraft). As an example an F-35 may use a M83723/72W1212N connector that is also used in a V-22, F-16, F-15, C-130, C-17, etc. They are very common in industry. In most cases, the US government only approves certain suppliers and manufactures who are listed on the Qualified Parts List (QPL) for a particular part number.

- A ***non-standard part*** is based on a military part but is slightly changed from the military specification. As an example, an OEM such as Lockheed Martin may want to use a military connector in a bulkhead penetration. Because the depth of a bulkhead is a little bit thicker than the size of the military connector, Lockheed Martin designs a new connector based on the military connector but increases its size slightly so it can fit in the penetration. In this case, Lockheed Martin writes and controls a specification and gives the part a new part number. Typically an OEM will also designate which suppliers are approved to manufacture non-standard parts. The specification is typically called a Source Control Drawing or Specification Control Drawing.

- The good thing about *non-standard* parts is that they fill a need for the OEM and the OEM controls the specification and the suppliers who can build them. The bad thing is that these parts are typically more expensive since fewer are required throughout the industry and in many cases are used on only one aircraft.

- The third category of parts is *Commercial Off The Shelf* (COTS). These parts are designed and controlled by a manufacturer. Based on the need for the items in the commercial and military industry and marketing studies, a manufacturer will design and make its own part numbers. The manufacturer controls revisions to the specification and when to release revisions. Neither the US military nor an OEM for military aircraft has control of these parts.

- The good thing about these parts is that they are typically readily available and are less expense than both *Standar*d and *Non-Standard* parts. They are less expensive because they are not qualified by either the US military, SAE, or an OEM. The bad thing about them is that the manufacturer can make changes to their own specification at anytime without any approval from an outside source. They are also sole source for their COTS parts so they control the price and distribution.

CHAPTER

3

Wire Selection

- When an aircraft electrical system is designed the starting point is at the system level. A system schematic shows the larger components and how they are connected together. In the system schematic, they are simply connected together with a line but the size and wire specification are not called out. Also the system schematic does not show where there are breaks in the wire run, such as when a wire goes through a bulkhead via two connectors. Even though it is a very basic design, the types of signals that the wire will carry (i.e. AC, DC, data bus, RF, etc.) are known. Additionally, the schematic shows where shielded wires (or cables) are needed as well as twisted pairs, triplets, quads, etc.

- The next step in the wire selection process is based on the type of signal a conductor is carrying. A good Computer Aided Drafting (CAD) software automatically calculates the current carrying capacity of each gauge size. Based on the required current, a wire type is selected. Generally, the smallest gauge wire is selected that can successfully carry the required amount of current. SAE AS50881 lists the current carrying capacity for most common wire gauges.

- In the 1970's the main type of wire chosen in the aircraft industry was Kapton™ insulated wire. Kapton is a Dupont™ trade name. Now the wires of choice are typically: TKT (Teflon/Kapton/Teflon), Teflon™, Tefzel™, and Cross Link Tefzel™. Typically, the Air Vehicle Specification for an aircraft lists the type of wire insulation that will be used throughout the aircraft. As an example, the OEM might decide that TKT will be used throughout the aircraft with some exceptions such as RF cables and Teflon™ insulated wire in boxed assemblies.

- Based on the system schematic design, the type of signal a conductor is carrying, the amount of current in the circuit, and the type of wire insulation chosen for the aircraft, wire harness design engineer select wire part number to use. Using a 3D CAD system, the wire paths are specified throughout the aircraft. In addition, connector disconnects will determine when a wire goes through a bulkhead. Each wire in a wire segment is then uniquely identified (see Chapter 4 Wire Identification) and a detailed wire diagram is developed. The wire diagram shows all wire segments, identification numbers, and disconnects.

CHAPTER

4

Wire Identification

- Every wire segment on an aircraft should have its own unique identifier. Even the shield of shielded wire has its own unique identifier. Put simply, every conductor of current is uniquely identified. As an example, a twisted pair that is shielded and jacketed contains three conductors: the twisted pair and the outside shield.

- Likewise, the marking on a wire/cable is uniquely identified. SAE AS50881 describes how a wire should be identified and marked. A wire identifier contains:

    1) The circuit function letter
    2) The wire number
    3) The segment letter
    4) The wire gauge.

Example: P215A4 is a single conductor wire.

- There is an alternative method for identifying wire. It consists of listing the following information: the letter “W” followed by the wire harness number, wire identification number, and wire gauge. Some examples are shown below.

Single Conductor

- ➢ W192-06-22

Twisted, Shielded Jacketed Pair

- ➢ W192-019-22
- ➢ W192-020-22
- ➢ W192-600-SH

CHAPTER 5

Connector Selection

- InterConnect has been in business now for 21 years. It seems that after such a long time, we would have entered every military connector part number ever developed into our Enterprise Resource Planning (ERP) system. Unfortunately, this is not true. Almost every week we enter new military connector part numbers into our system. As of the date we released this eBook we have identified over 3,200 military connector part numbers. With so many possible part numbers, how does an engineer ever decide which part number to use in designing a wiring harness?

- The good news is that there are only a few common series of military connectors. Based on over 20 years of experience in the military aerospace industry the most common series of military connectors are:

  - MIL-DTL-38999 (formerly MIL-C-38999)
  - MIL-DTL-83723 (formerly MIL-C-83723)
  - MIL-DTL-26482 (formerly MIL-C-26482)
  - MIL-DTL-5015 (formerly MIL-C-5015)
  - MIL-DTL-81511 (formerly MIL-C-81511)
  - MIL-DTL-24308 (formerly MIL-C-24308)

Keep in mind there are other series of connectors as well as Non-Standard connectors and COTS connectors.

- In general it is best to have few connectors in an area, thus, it is best to select a connector series that has as many contact cavities as possible. A favorite in the military industry is the MIL-DTL-38999 connector series since these connectors typically have many contact cavities. The next step is to analyze the following information and decide which systems (i.e. wires) you want to go through a connector:

  1) The number of wires.
  2) The size or gauge of each wire.
  3) Which wires should not go through a connector because of the need to physically separate redundant systems (especially flight control wires) from one another.

- Once this information is known, a wiring harness engineer then reviews different insert arrangements (especially the size of the contact cavities for a connector) and, based on wire and contact sizes, the engineer chooses a connector. It is best to start with normal polarization for the connector. If the same basic connector part number is used in the vicinity of another connector then a different polarization should be selected.

CHAPTER 6

Reference Designators

- A reference designator identifies a component in a system schematic and wiring diagram. For the purposes of this eBook, we will only discuss components common to aircraft electrical wiring harnesses. Reference designators for connectors typically start with:

  1) A four digit number which represents the primary system and subsystem for the wires that go through the connector.
  2) Either the letter “P’ or “J” representing (Plug or Jack).
  3) A three or four digit number.

Example: a reference designator might be 3315P706. It will be connected to 3315J706. A Jack is a connector that is mounted to the airframe. It can be fastened to the airframe by methods such as securing it’s flange using screws and nuts or by nut rings. A Plug connector mates to a Jack. It is not physically mounted to the airframe except by being connected to the Jack.

- There are a few other components (and their associated reference designator designations) that may be found in wiring harnesses. Splices (also called wire ties) have a reference designator notation of WT. Other components include:

    - Resistors (notated by R)
    - Capacitors (notated by C)
    - Ground Blocks (notated by GD)
    - Diodes (notated by CR)
    - Switches (notated by S)
    - Relays (notated by K)
    - Circuit Breakers (notated by CB)

CHAPTER

7

Shield Termination

- Shield termination refers to how the shield of a shielded wire is terminated to another component. There is a wide variety of termination methods including:

    1) Attaching a solder sleeve and jumper wire to the shield then the jumper wire is connected to the connector's backshell.
    2) Attaching a solder sleeve and jumper wire to the shield then routing the jumper wire to a contact cavity in a connector.
    3) Attaching a solder sleeve and jumper wire to the shield and the jumper wire is "daisy chained" to the jumper wire of other shields.
    4) A piece of shrink tubing is placed over a shield and it is floated (not connected) to any conductor or ground point.

- The purpose of a shield in a shielded wire is to eliminate the Electromagnetic Interference (EMI) that is caused by the electrical current in the conductor of a wire. Likewise, a shield limits EMI caused by other nearby wires. Shields eliminate crosstalk between wires so you have a clear signal.

- The most common practice in the aerospace industry is to terminate the shields to a jumper wire then the jumper wire is connected to a ground point. In many cases the ground point is the backshell of a connector and ultimately the air frame.

CHAPTER 8

Harness Bundle Protection

- A common question in the aerospace industry is, “How should you hold a bundle of wires together?” There are five main methods used in the aerospace industry:

    1) String Tie
    2) Tie Wraps
    3) Expandable Braided Sleeving
    4) Shrink Tubing
    5) Taped and Braided

- All of these methods have advantages and disadvantages. The least costly method (and the lightest weight) is string ties. The best looking wiring harnesses are braided (especially with a variety of colors). The remainder of this chapter simply lists the advantages and disadvantages of each method. Typically an OEM will specify which method to use.

String Tie

a. Advantages
   1) Low cost.
   2) Easy to modify and repair.
   3) Low weight.
   4) Stays tied over decades.

b. Disadvantages
   1) Wire bundle is not protected.
   2) Some wires can accidently move out of the bundle during installation or retrofit programs.
   3) Wire bundles can potentially lose their shape.
   4) Increased manufacturing hours by manually tying string. ties

Tie Wraps

a. Advantages
   1) Low cost.
   2) Easy to modify and repair.
   3) Does not add much weight.
   4) Can be installed quickly and therefore reduce the manufacturing process.

b. Disadvantages
   1) Wire bundle is not protected.
   2) Can break off and lead to Foreign Object Debris (FOD).
   3) Conflicts with the requirements of SAE AS50881.

Expandable Braided Sleeving

a. Advantages
   1) Offers some protection to the wire bundle

b. Disadvantages
   1) Adds weight
   2) In most cases is not a close fit around a wire bundle
   3) Takes time to push a wire bundle through the expandable braided sleeving
   4) Material can be expensive

Shrink Tubing

a. Advantages
   1) Offers very good protection to the wire bundle
   2) Lasts a long time

b. Disadvantages
   1) Adds weight
   2) Takes time to push a wire bundle through the shrink tubing
   3) Takes time to shrink the tubing over the bundle
   4) Cannot access the wires under the shrink tubing after it is shrunk
   5) Material can be expensive

Braided

a. Advantages
   1) Offers excellent protection to the wire bundle.
   2) Increases the physical appearance of the wiring harness.
   3) Lasts a long time.
   4) Compacts the wire bundle to aid in installation
   5) Color coded braid helps easily identify a wiring harness.
   6) Offers electromagnetic interference (EMI) protection if metal braid is chosen.

b. Disadvantages
   1) Adds weight.
   2) Is expensive to hand braid each wiring harness.
   3) If additional wires are desired in a wiring harness they have to be “piggy-backed” (individually braided and ran outside of the braid) of the existing bundle assembly.

CHAPTER 9

Testing

- Typically testing of aircraft electrical wiring harnesses is done by using automatic test equipment commonly called wiring analyzers. There are many companies who make wiring analyzers. Programs are written for wiring analyzers to test each separate wiring harness. Unique programs tell the equipment what tests to run, how much current, voltage, dwell time to use as well as the order in which to run the tests. A technician connects the wiring analyzers to the wiring harness to be tested using adapter cables.

The two most common tests to run are:

1) Continuity
2) Insulation Resistance

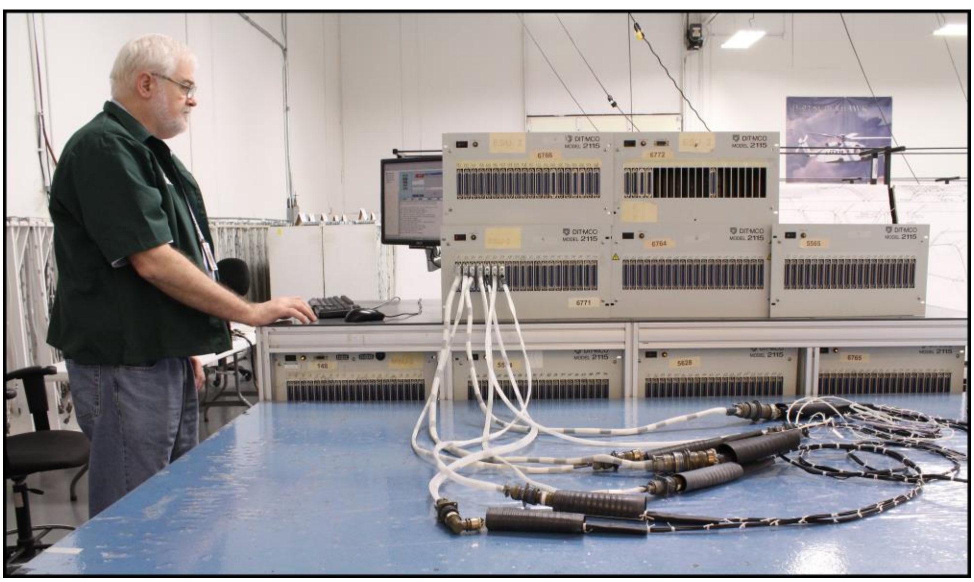
- ***Continuity*** tests make sure each wire is hooked-up or connected in accordance with the design. Thus if a wire is supposed to be connected from connector 1 at pin 13 to connector 2 at socket 34 the continuity test will verify that wire is there. Typical continuity tests are performed at 0.5 Amps with a constant voltage and a dwell time of 0.2 seconds minimum.

- *The* second type of test is the ***insulation resistance*** test (also called a meg ohm test). This test checks for short circuits. As an *example*; if two wires have nicks in the insulation and are close to one another, the insulation resistance test will show a short circuit. If a connector was not manufactured correctly and there is not enough material to separate two contacts, the insulation resistance test will show this short circuit as well.

- Typical *insulation resistance* tests are run at 1500 VDC with a constant current and dwell time of 0.15 seconds minimum. The insulation resistance test does what the name suggests; makes sure there is enough resistance between two or more conductors so that a short circuit will not result. Typically, if the resistance is greater than 100 Meg Ohms then it passes the test.

- Most OEM’s specify how to test electrical wiring harnesses. The common military test standard is MIL-STD-202.Wiring analyzers can also do other tests such as:

  - Empty contact cavity test
  - AC dielectric test
  - Light lights
  - Energize relays
  - Measure capacitance
  - Measure resistance
  - Ensure that diodes are working correctly



CHAPTER 10

Industry Standards

- There are many aerospace wiring harness manufacturing industry standards that a wiring harness design engineer should be familiar with. This eBook will not go into detail on any of them. It will, however, list the most common and provide a brief description.

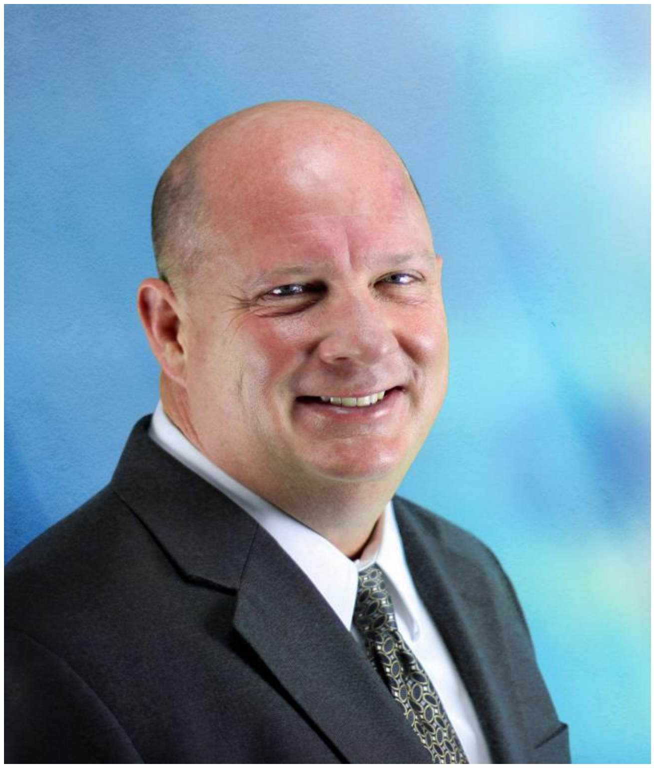
1) AS9100C - AS9100 is a widely adopted and standardized quality management system for the aerospace industry.
2) IPC/EIA J-STD-001C - Requirements for Soldered Electrical and Electronic Assemblies. In the 1990's the common soldering standard was MIL-STD-2000.
3) IPC-A-610 - Acceptability of Electronic Assemblies.
4) IPC/WHMA-A-620B Requirements and Acceptance for Cable and Wire Harness Assemblies.
5) NAVAIR 01-1A-505-1 Aircraft Wiring Harness Installation and Repair Practices (Note the US Air Force's manual 01-1A-14 was superseded by NAVAIR 01-1A-505-1 and the US Army manual 1-1500-323-24-1 was also replaced by NAVAIR 01-1A-505-1).

SUMMARY

- This eBook was primary written for recently graduated aerospace wiring harness engineers. It can also serve as a very good source of information for engineers who have been designing wiring harnesses for many years, as well as technicians, buyers, supervisors and program managers. A wide variety of information was presented from “How to get started”, to “*Standard* and *non-standard* parts”, to” How to select wires and connectors”, “Testing”, and finally “Common aerospace wiring harness manufacturing specifications and standards”.
- InterConnect Wiring hopes that this eBook was informative. If you have comments or questions about this eBook please contact us. Additionally, if you want to be placed on distribution for future eBooks, Blogs, and White Papers, please complete the following form.

Share this eBook

g+ f t in



Created by: John Ashour, President and Founder of InterConnect Wiring L.L.P.

Share this eBook

g+ f t in

“ We do the most critical tasks for our customers better and faster than they once thought possible. ”

- InterConnect Wiring

TOUR OUR FACILITY

TAKE A TOUR

We specialize in helping aerospace companies who are behind schedule on their electrical wiring harness requirement "get caught-up" in a hurry.

[Request a Tour]

A Publication of

InterConnect